ANDROSCOGGIN MILLS
PHOSPHORUS REDUCTION STUDY

Prepared for:

International Paper – Jay, ME
MeadWestvaco – Rumford, ME
Nexfor-Fraser – Berlin, NH

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EXECUTIVE SUMMARY

The Maine Department of Environmental Protection (DEP) is considering new phosphorus license limits for the three paper mills that discharge to the Androscoggin River – International Paper (IP) in Jay, ME, MeadWestvaco (MWV) in Rumford, ME; and NexforFraser (Fraser) in Berlin, NH. This report evaluates potential technologies for reducing total phosphorus (TP) concentrations in the discharges from those mills, and the associated capital and operations and maintenance (O&M) costs of those technologies.

Based on our review of other U.S. mills, 1 mg/L is typically the lowest consistently achievable TP permit limit for a conventional activated sludge treatment system, requiring a normal effluent TP concentration of 0.7 to 0.8 to allow for effluent variability. Mills with effluent TP concentrations consistently less than this typically achieve these levels because their treatment systems were oversized, and/or employed tertiary treatment. Oversized treatment equipment, in the form of large aeration basins and/or secondary clarifiers, allows some mills to operate with very low residual dissolved P concentrations. Tertiary treatment minimizes effluent TSS and particulate P loadings, at substantial cost.

Of the three Androscoggin mills, both MWV and IP often achieve TP levels less than 1 mg/L. The Fraser mill just restarted operations in April 2003 after a 20 month shutdown, with modifications to the previous pulping operations, and therefore will need to operate for several more months before adequate data is available to begin to assess their performance and capabilities. Prior to setting permit limits at any of the mills, it is suggested that an additional one to two years of monitoring and data gathering should be implemented. This monitoring period would allow the stakeholders to gain a better understanding of the long-term capabilities of each mill to control phosphorus, and the potential limitations of control technologies that may be applied on a trial basis.

There are numerous TP reduction and control technologies available. Of these, four were considered applicable to wastewater discharges at the three mills:

1. Process Control Enhancements (PCEs) such as phosphorus monitors, turbidity transmitters, routine microbial analysis and anthrone polysaccharide testing, etc.;

2. Polymer addition to the secondary clarifier;

3. Tertiary treatment using dissolved air flotation (DAF) with polymer after the secondary clarifier; and

4. Tertiary treatment using DAF and chemical precipitation of soluble phosphorus with metal salts.

The construction of DAF technology, while providing the potential to achieve significant effluent TP reductions, would result in substantial capital and O&M costs, as shown in Table ES-1 and ES-2 below. Significant reductions in effluent phosphorus concentrations may be possible without the construction of a DAF, and at substantially lower costs.

Smaller reductions to TP are possible through more detailed monitoring (e.g. one to two years worth), and perhaps the implementation of process control enhancements and polymer addition systems. The data from this study period could then be used to determine the feasibility of future TP reductions.

Table ES-1: Summary of Costs for Various Phosphorus Control Technologies

Technology	Range of Total P Reduction[1]	Capital Cost [2,3]	Annual O&M Cost [2,3]	Annualized Cost [4]
DEP Baseline	NA	$0	$0	$0
Process Control Enhancements (PCEs)	3 – 20%	$410,000	$80,000	$130,000
PCEs and Polymer in Secondary Clarifier[5]	10 – 35%	$750,000	$390,000	$470,000
DAF with Polymer Only	30 – 45%	$27,000,000	$2,000,000	$5,100,000
DAF with Chemical Precipitation[3]	40 – 67%	$40,000,000 - 47,000,000	$12,000,000 – $23,000,000	$16,000,000 - $28,000,000

Notes:

1) Range of total P reduction for all three mills combined, based on qualitative assessments of what effluent TP levels mills may be able to achieve, based on knowledge of WWTP characteristics, past effluent analyses, and limitations of various control technologies. It was assumed that these reductions represent long term averages, and not permit limits, since operating levels would need to be lower than permitted levels to allow for effluent variability.

2) Total cost for all three mills.

3) Capital costs for DAF with chemical precipitation increase with increasing TP reductions due to the requirement for greater sludge handling equipment. Annual O&M costs are also greatly affected by the target phosphorus concentration in the case of chemical precipitation. Lower phosphorus concentrations result in disproportionately higher metal salt concentrations, sludge generation, handling, and disposal, and caustic requirements. The lower costs equate to lower TP reductions, and the higher costs relate to the highest (most stringent) TP reductions.

4) Capital costs were amortized at 7.5% over 15 years and added to annual O&M costs to develop an annual cost of ownership and operation. Capital recovery factor for capital costs is 0.1133 using these assumptions.

5) IP is already adding polymer in the summer months in order to comply with strict summer TSS limits imposed by the Town of Jay. Their costs for polymer addition are not included in this total.

Table ES-2: Summary of Cost Estimates for Various Phosphorus Removal Rates

Reduction Level[1] (Technology Required)	Capital Cost [2]	Annual O&M Cost [2,3]	Annualized Cost [4]
DEP Baseline	$0	$0	$0
1/6 Reduction[1] (PCEs and polymer in sec. clarifiers)	$640,000	$370,000	$440,000
1/3 Reduction[1] (PCEs and DAF with polymer)	$27,000,000	$2,000,000	$5,1000,000
40% Reduction[1] (DAF with precipitation)	$40,000,000	$12,000,000	$17,000,000
50% Reduction[1] (DAF with precipitation)	$43,000,000	$16,000,000	$21,000,000
67% Reduction[1] (DAF with precipitation)	$47,000,000	$23,000,000	$28,000,000

Notes:

1) Total P reduction from DEP baseline for all three mills combined. It was assumed that these reductions represent long term averages, and not permit limits, since operating levels would need to be lower than permitted levels to allow for effluent variability.

2) Total cost for all three mills.

3) Capital costs for DAF with chemical precipitation increase with increasing TP reductions due to the requirement for greater sludge handling equipment. Annual O&M costs are also greatly affected by the target phosphorus concentration in the case of chemical precipitation. Lower phosphorus concentrations result in disproportionately higher metal salt concentrations, sludge generation, handling, and disposal, and caustic requirements. The lower costs equate to lower TP reductions, and the higher costs relate to the highest (most stringent) TP reductions.

4) Capital costs were amortized at 7.5% over 15 years and added to annual O&M costs to develop an annual cost of ownership and operation. Capital recovery factor for capital costs is 0.1133 using these assumptions.

1. INTRODUCTION

1.1 BACKGROUND

The Maine Department of Environmental Protection (DEP) is considering new phosphorus license limits for the three paper mills that discharge to the Androscoggin River – International Paper (IP) in Jay, ME, MeadWestvaco (MWV) in Rumford, ME; and NexforFraser (Fraser) in Berlin, NH. The emphasis on phosphorus is a result of the "Androscoggin River Alternative Analysis for TMDL" prepared by the DEP in February 2002. The study focused on Gulf Island Pond, a large impoundment on the Androscoggin River that extends from 14 miles from Lewiston to Turner, and has a maximum depth of 80 feet. Gulf Island Pond does not meet applicable criteria for dissolved oxygen levels and the yearly occurrence of algae blooms.

All three paper mills discussed in this report discharge upstream of Gulf Island Pond. In 1993, the three mills and an electric utility company that operates the Gulf Island Dam (the source of the Gulf Island Pond Impoundment) installed an oxygen diffuser five miles upstream of the dam to increase dissolved oxygen levels in deeper portions of the pond. The oxygen diffuser is called the Gulf Island Pond Oxygenation Project (GIPOP). Despite the installation and operation of the GIPOP, low dissolved oxygen concentrations persist in some of the deeper portions of Gulf Island Pond.

Legislation has been proposed that would provide the DEP with the authority to adopt a compliance depth for dissolved oxygen in stratified riverine impoundments, including Gulf Island Pond. The DEP must evaluate and consider physical, chemical, biological, and economic factors prior to establishing a compliance depth. The DEP has chosen to establish a stakeholder process to support and participate in the consideration of the factors in the Department's decision.

Several treatment step options have been developed through the stakeholder process for reducing point sources of phosphorus loading to the Androscoggin River. The options include reductions in overall point source mass loading of TP to the river by: 1/6, 1/3, 40%, 50%, and 67%. This report provides all of the stakeholders with information regarding the implementation of a range of possible alternatives to reduce effluent total phosphorus loadings from the three Androscoggin mills.

The purpose of this report is to provide an evaluation of potential technologies for reducing phosphorus concentrations in the discharges from these three mills, and the associated capital and O&M costs of those technologies.

1.2 THE PURPOSE AND FATE OF PHOSPHORUS IN BIOLOGICAL TREATMENT SYSTEMS

The primary purpose of a conventional activated sludge treatment system is to remove biochemical oxygen demand (BOD) and total suspended solids (TSS) from wastewater. TSS and particulate BOD are removed through settling of solids in the primary clarifier, and settling of microorganisms (referred to as activated sludge or mixed liquor suspended solids) in the secondary clarifier. BOD is removed as bacteria degrade organic compounds. The bacteria in a biological treatment system require some dissolved phosphorus in the wastewater in order to metabolize organic matter and reproduce by generating additional cell mass. A ratio of one part P to 100 parts BOD is typically required to provide adequate phosphorus. If adequate phosphorus is not available, several things may occur:

- Soluble BOD may bleed through the treatment system because the metabolism of the bacteria is hindered, and they can not properly degrade the organic wastes. This may lead to violations of the mill's permitted BOD limit.

- Sludge settling issues may develop through a phenomenon known as polysaccharide bulking, or through the overgrowth of filamentous bacteria. Polysaccharide bulking causes sludge solids to form a viscous, gelatinous coating that results in very poor settling. During outbreaks of filamentous bacteria, the sludge tends to form large, fluffy particles that also will not settle or compact well. Regardless of the cause, poor settling sludge may lead to violations of the mill's permitted TSS limit, as well as their BOD limit (since the sludge solids that flow out of the secondary clarifier represent particulate BOD).

In municipal wastewater, an excess of P is available in the wastewater. However, at most paper mills, there is not typically enough phosphorus in the wastewater to maintain a healthy, well-settling biomass. Therefore, phosphorus is intentionally added to the wastewater (as is nitrogen). In treatment plants that operate with very long sludge ages, little or no phosphorus may be required, since it is continuously recycled as bacteria decay and release phosphorus from their cells. Regardless of whether phosphorus is added by chemical addition or recycled by bacterial decay, some level of dissolved phosphorus must always be present in the wastewater in order to maintain a healthy biomass and well operating treatment system.

Phosphorus in wastewater may be in one of two principal forms: dissolved phosphorus (either ortho-P, or polyphosphates such as detergents); and particulate phosphorus (bacterial cell mass or inorganic precipitates). In order to control phosphorus in the effluent, both of these forms of phosphorus must be controlled. Particulate P may be removed from the wastewater through clarification, flotation, or filtration. Bacterial cells typically contain 1 to 2 percent phosphorus, so that every 10 mg/L of bacterial solids in the effluent results in 0.1 to 0.2 mg/L of TP in the effluent. Levels of dissolved phosphorus can either be reduced by controlling the residual ortho-P concentration in the wastewater, and/or adding metal salts or other chemicals to precipitate the dissolved P to form particulate P. Because a residual ortho-P concentration of 0.3 to 0.6 mg/L is typically required to support a healthy biomass in most treatment plants, and effluent suspended solids contain additional phosphorus, most pulp and paper mills are limited to TP concentrations of 0.7 to 1.0 mg/L without tertiary treatment.

1.3 CHARACTERISTICS OF THE THREE ANDROSCOGGIN MILLS

A brief description of the production processes, flows, loads, and wastewater treatment techniques at the three Androscoggin mills is provided below.

1.3.1 IP - Jay

The IP mill is an integrated pulp and paper mill. They operate bleached kraft and stone groundwood pulp mills. The mill produces 1,500 tons per day (tpd) of various types and grades of paper, and produces market pulp. The mill operates both alkaline and non-alkaline paper machines.

The wastewater treatment plant (WWTP) is an activated sludge system consisting of two primary clarifiers, an aeration basin with mechanical aerators, and two secondary clarifiers. The permitted effluent flow is 51 million gallons per day (MGD). Typical flow from the plant is approximately 43 MGD. In addition to wastewater flows from the pulp and paper mills, the WWTP accepts stormwater from the mill, and treats approximately 3 to 4 MGD of wastewater from the nearby Wausau-Mosinee

Papers Otis Mill. The WWTP operates at a relatively long sludge age of 15 days, allowing low residual phosphorus levels to be maintained.

The WWTP adds polymer to the secondary clarifiers in the summer months to meet their stringent Town of Jay TSS levels. This also appears to have a beneficial effect on TP concentrations. The TP concentration typically ranges from 0.7 mg/L to 1.0 mg/L, and in the summer has been as low as 0.5 mg/L. The WWTP has also tried to operate without supplemental phosphorus addition. While they were able to reduce their effluent dissolved P concentration during this trial period, the total P concentration remained virtually unchanged due to impaired sludge settling characteristics, and resulting increase in particulate P concentrations.

1.3.2 MeadWestvaco - Rumford

The MWV Rumford mill is an integrated pulp and paper mill. They operate bleached kraft and stone groundwood pulp mills. The mill produces 1,500 tpd of various types and grades of paper with four paper machines, and produces about 300 tpd of bleached hardwood kraft market pulp with a market dryer.

The WWTP is a high rate activated sludge system consisting of one primary clarifier, an aeration basin with coarse bubble aerators and spray coolers, and three rectangular secondary clarifiers. The permitted effluent flow is 34 MGD. Typical flow from the plant is 31 MGD. Historical effluent TP concentrations have typically been around 0.85 mg/L.

Over the past few years, mill personnel have made significant efforts to monitor and control the effluent TP concentration, including: preparing a mass balance for all sources of P within the mill; and sampling and analyzing for phosphorus residual concentrations every eight hours and adjusting to a target orthophosphate level that will not upset their activated sludge treatment process.

Because the Rumford WWTP is small and needs to operate at a low sludge age (6-8 days), it may be difficult for plant operators to reduce the orthophosphate concentration below 0.4 mg/L without risking a sludge bulking episode. The mill is currently trialing residuals below 0.4 mg/L and does not know without an appropriate trial period whether these unproven residual levels may be maintained in their WWTP. The mill has invited DEP to form a joint Pollution Prevention team to trial reduced P residuals.

1.3.3 Fraser - Berlin

NexforFraser operates separate pulp and paper mills located on opposite sides of the Androscoggin River- the Burgess pulp mill in Berlin, and the Cascade paper mill in Gorham. The Burgess mill produces about 750 tpd of bleached hardwood pulp, of which about 350 tpd is market pulp. Only the Burgess mill is considered in this report, since the Cascade mill does not add phosphorus to their wastewater treatment system.

The Burgess mill WWTP is an activated sludge system consisting of one primary clarifier, two aeration basins with mechanical aerators, and one secondary clarifier. The sludge age averages about 10 days. The permitted effluent flow is 18 MGD. Typical flow from the plant is 16 MGD.

The Burgess mill was shut down in August 2001 and restarted in April of 2003 under new ownership, so there is not a significant amount of recent operating data at this time. The mill has also made modifications to the previous pulping operations. The mill will need to operate for several more months before adequate data is available to begin to assess their performance and capabilities.

1.4 PHOSPHORUS PERMIT LIMITS IN OTHER AREAS OF THE U.S.

Effluent P limits have been imposed on pulp and paper mills in certain parts of the country, including the Great Lakes region of Michigan and Wisconsin. Effluent TP permit limits varied from 1 mg/L to 3.5 mg/L. The only exception to this is the IP-Ticonderoga mill which discharges to Lake Champlain and has a TP limit of 0.5 mg/L, and utilizes tertiary treatment to comply with this restrictive limit.

Based on our review, a TP permit limit of 1 mg/L is typically the lowest consistently achievable level for a conventional activated sludge treatment system. A permit limit of 1.0 mg/L requires mills to consistently operate at an effluent TP concentration of 0.7 to 0.8 mg/L to allow for effluent variability. Mills with effluent TP concentrations consistently lower than this typically achieve these levels because their treatment systems are oversized and/or employ tertiary treatment. Of the three Androscoggin mills, both MWV and IP often achieve TP levels less than 1 mg/L. The Fraser mill just restarted operations in April 2003 after a 20 month shutdown, so there is not a significant amount of recent operating data at this time.

2. POTENTIAL METHODS FOR CONTROL AT THREE ANDROSCOGGIN MILLS

Numerous control technologies are available for the reduction of effluent TP in large industrial wastewater discharges. Four technologies (process control enhancements, polymer addition to the secondary clarifier, and DAF with and without chemical precipitation) are described below. Other technologies that were screened, but not evaluated in this report included:

- Enhanced biological phosphorus removal. This treatment technology is used widely in the municipal arena. However, it can only typically achieve TP concentrations of 1 to 2 mg/L, and therefore is not appropriate for the pulp and paper industry.

- Simultaneous precipitation. This technology consists of adding metal salts to the secondary clarifier to precipitate soluble phosphorus. While this is commonly applied to municipal wastewater, it has not been applied with success to pulp and paper wastewater for the following reasons:

    - The creation of metal sludges results in significant increases in the mixed liquor suspended solids (MLSS), potentially resulting in an unacceptable loading rate to the secondary clarifiers, and difficulties in dewatering and/or incinerating sludge.

    - The precipitation of phosphorus and recirculation of unreacted metal salts to the aeration basin may cause unacceptably low phosphorus residuals in the aeration basin.

- Sand filtration. This technology is not proven on pulp and paper wastewater. Sand filters have a potential to plug during an upset event.

- Tertiary clarifiers. These devices have been shown to provide reductions in effluent TP. However, capital and O&M costs would be similar to DAF systems, and tertiary clarifiers would typically occupy a much larger footprint than DAF equipment. Because the mills have space constraints, DAF systems were selected in lieu of tertiary clarifiers for further analysis.

- BOD Reductions. By reducing influent BOD loadings, the WWTP may be able to reduce the amount of phosphorus that they add to the wastewater. However, this strategy does not offer meaningful effluent TP reductions since they will still need to maintain the same level of residual dissolved phosphorus in the aeration basin regardless of the BOD loading.

- CoMag. This innovative technology uses conventional precipitation techniques coupled with addition of powdered magnetite and high strength magnets to provide rapid settling and lower total phosphorus concentrations than can typically be achieved using conventional techniques. However, this technology has not advanced to the point that it could be readily applied to a flow as large as that at a paper mill.

- Flow reductions. The three Androscoggin mills are relatively old, integrated mills that have extremely complex process piping and sewer networks. The mills also cover huge areas, making it difficult to consolidate mill processes without lengthy pipe runs. Therefore, any efforts at flow consolidation or reduction would be difficult and expensive. Any flow reductions, if possible, would require significant engineering investigations that are well outside the scope of this report. It's important to note that integrated mills, particularly those that make coated and uncoated paper, have alkaline and non-alkaline paper machines, make groundwood and kraft pulp, and route stormwater to the treatment plant, tend to use significantly more water per ton than market pulp mills. Therefore water use comparisons between widely varying types of mills, old and new, do not represent useful, apples to apples comparisons.

2.1 PHOSPHORUS REDUCTION TECHNOLOGIES APPLICABLE TO THE ANDROSCOGGIN MILLS

2.1.1 Process Control Enhancements

Process Control Enhancements (PCEs) are monitoring and control technologies that may enable the mills to reduce phosphorus levels while still providing effective reduction of BOD and TSS, and avoiding sludge bulking conditions. Compared to other potential capital upgrades, PCEs are relatively low cost and easy to implement. They are tools that allow operators to better control P addition to the aeration basin, and solids loss from the secondary clarifiers. By implementing these enhancements, the three mills may be able to reduce their combined phosphorus loadings by up to 20 percent collectively. PCEs may include one or more of the following alternatives described below.

2.1.1.1 On-line Ortho-phosphate Analyzers

The purpose of a phosphate analyzer is to continuously monitor and track the dissolved phosphorus concentration so that it can be maintained at the lowest possible level that will support a healthy biomass. There is, of course, no substitute for an activated sludge system with significant excess capacity when it comes to trimming P addition and smoothing our loading variations.

Ortho-P analyzers consist of a sample preparation system (pump, membrane filter, cleaning and backwash controls), and a phosphate analyzer that determines dissolved P levels using similar techniques to those used currently by the mills. Typically the analyzers are accurate and dependable, as long as they stay free of debris, so the performance of the sample preparation system is critical to the success of the analyzer. Routine cleaning and maintenance are also crucial. The sample preparation systems are designed for use in mixed liquor. However, the sample would likely be collected from the final effluent, in order to minimize the potential for fouling, and prolong the life of the analyzer. For this reason, final effluent applications have proven more reliable than mixed liquor applications. To date this technology has had limited application in the pulp and paper industry.

2.1.1.2 Sludge Blanket Level Transmitters

These transmitters would allow the treatment plant operators to continuously monitor sludge blanket levels to check for sludge bulking. Typically, blanket levels are only checked once or twice per day by the operators using a sludge judge or similar device. More frequent monitoring would enable the operators to track the blanket heights more effectively, and quickly take action if necessary. One of these transmitters could be placed in each clarifier at mills with circular clarifiers (Burgess, Jay), while two or more transmitters would likely be required for each of the long rectangular clarifiers such as those in Rumford.

Sludge blanket level transmitters have had a history of mixed results. However, Woodard & Curran treatment plant operators have had good luck with them, particularly at a pulp and paper mill application in Madison, Maine. The technology continues to improve with time, and the latest generation of transmitters are producing some good results and providing significant environmental and economic benefit.

2.1.1.3 On-line Turbidity Transmitters

The purpose of a turbidity transmitter is to continuously monitor the effluent suspended solids concentration, so that trends can be observed and corrective actions can be taken, if necessary. These devices can provide an effective early warning for secondary clarifier upset. Also, effluent TSS typically correlates well with particulate P. As with many on-line instruments, the technology is improving rapidly and beginning to enjoy success in both municipal and industrial applications.

2.1.1.4 Anthrone Polysaccharide Analysis

If wastewater is deficient in nutrients such as nitrogen and phosphorus, bacteria are not able to form additional cell mass, so they will convert carbohydrates into an excessive exocellular polysaccharide layer. If nutrient deficient conditions persist, the polysaccharide layer can grow to the point that the sludge will begin to bulk, and mixed liquor will no longer settle. By regularly monitoring polysaccharide levels of activated sludge mixed liquor, operators can increase nutrient levels as necessary to avoid sludge bulking. This is an essential component of maintaining an activated sludge system at reduced P addition rates.

2.1.1.5 Sludge Microbiological Analysis and Filament Typing

Nutrient deficiencies can also promote the growth of filamentous organisms. Regular microbial analysis and filament typing can determine if conditions are promoting the growth of filaments, and increase nutrient levels, if necessary. This includes routinely sending samples out for expert microbial analysis and/or training operators to become proficient at using the microscope and requiring its use and documentation on a regular basis.

2.1.2 Polymer Addition to the Secondary Clarifier

Polymer can be added to the secondary clarifier to promote coagulation and flocculation of sludge and reduce the concentration of total suspended solids (TSS) in the supernatant. A decrease in TSS of 10 mg/L can reduce total phosphorus concentrations from 0.05 to 0.15 mg/L, depending on the proportion of active biomass in the supernatant. The Jay mill already adds polymer to the secondary clarifier during the summer, in order to control TSS. This decreases the average TSS concentration to about 30 mg/L in the summer from greater than 40 mg/L during the remainder of the year.

The advantage of this technology is that it does not require a significant capital investment, is relatively easy to monitor and control, and it improves effluent BOD, TSS, and particulate phosphorus concentrations. Disadvantages include relatively high chemical costs (depending on the dose and type of polymer required), and the potential settling of some solids in the aeration basin, and difficulty pressing sludge with a lower primary to secondary solids ratio. Also, the benefits of polymer will vary depending on the nature of the mixed liquor suspended solids and effluent TSS concentrations at each plant. For example, the Fraser mill has a historical average effluent TSS concentration of about 40 mg/L, similar to IP, while the MWV mill has a historical average TSS concentration of about 20 mg/L, so polymer may not result in as great a gain at the MWV mill.

2.1.3 Tertiary Treatment Using Dissolved Air Flotation (DAF) to Remove Particulate P

There is a limit to the effectiveness of adding polymer to the secondary clarifiers (typically 10 to 20 mg/L TSS). In order to further reduce TSS concentrations, a dissolved air flotation system may be used. DAF units infuse air into a pressurized stream of wastewater. When the wastewater returns to atmospheric conditions, tiny air bubbles come out of solution, nucleating on and attaching to suspend solids, floating them to the surface. This process is highly effective in removing TSS, and can typically achieve a lower TSS concentration in a much smaller space than a conventional clarifier. Polymer must be added to DAF systems, typically at a concentration of 1 to 3 ppm. Advantages of this technology include effective reduction of TSS and particulate P. Disadvantages include high capital (millions of dollars) and O&M costs (power, polymer, operator attention, additional sludge disposal), and operational complexity compared to existing systems.

This technology may be combined with PCEs to reduce total phosphorus loadings from the three mills by up to 45 percent.

2.1.4 Tertiary Treatment Using DAF and Metal Salts to Remove Particulate and Dissolved P

Even if all of the TSS could be removed, phosphorus will still remain in solution. The most common way to remove dissolved phosphorus from solution is to add metal salts, such as ferric chloride, ferric sulfate or alum (aluminum sulfate). W&C performed bench-scale testing at both the Rumford and Jay mills to estimate the required dose of alum or ferric to achieve varying levels of effluent phosphorus. To achieve total phosphorus concentrations less than those achievable without adding metal salts, doses typically varied from 100 to 200 mg/L as Fe, depending on the required total phosphorus concentration. These high doses are consistent with other integrated kraft mills that have attempted to utilize this technology (see discussion of Stone Container - Ontonagon and IP-Ticonderoga in Section 3). Reasons for such high doses include: high paper mill wastewater alkalinity; and the presence of lignin and other ligands that complex with metal salts.

Advantages of this technology include the ability to achieve very low total phosphorus levels, and relatively simple chemistry. Disadvantages include high capital and O&M costs, and inability to incinerate sludges due to high metal content (and therefore a need for separate sludge handling and disposal methods). While several mills have run trials at the bench scale, the authors are unaware of any integrated kraft mill that adds metal salts on a full-scale.

This technology may be combined with PCEs to achieve total phosphorus concentrations as low as 0.2 mg/L.

2.1.5 Cost Estimates for Various Control Technologies at the Androscoggin Mills

Total capital and O&M costs for the four technologies are shown in Tables 2-1 and 2-2. Order of magnitude capital cost estimates were prepared for each of the proposed alternatives using a factored cost approach. Using the factored cost approach, vendor cost estimates were obtained for major equipment (DAF units, etc.), and unit costs were developed for other major components such as major concrete, major piping, major pumps, etc. Costs for other elements of design and construction (e.g. engineering, contractor's overhead and profit, contingency, painting, site work, minor piping, controls, etc.) were then determined as a percentage, or factor, of the major costs. This type of cost estimate is appropriate given the conceptual level of investigation and engineering used to develop the alternatives.

Annual operation and maintenance costs were developed using mill costs for labor, vendor costs for chemicals, and mill/market costs for sludge disposal associated with each alternative. In the case of Process Control Enhancements (PCEs), the O&M costs were based on continuous operation. For all other alternatives, O&M costs were based on operation of the equipment for 20 weeks per year (two week startup, four month operation, one week shutdown).

Table 2-1: Summary of Costs for Various Phosphorus Control Technologies

Technology	Range of Total P Reduction[1]	Capital Cost [2,3]	Annual O&M Cost [2,3]	Annualized Cost [4]
DEP Baseline	NA	$0	$0	$0
Process Control Enhancements (PCEs)	3 – 20%	$410,000	$80,000	$130,000
PCEs and Polymer in Secondary Clarifier[5]	10 – 35%	$750,000	$390,000	$470,000
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DAF with Chemical Precipitation[3]	40 – 67%	$40,000,000 - 47,000,000	$12,000,000 – $23,000,000	$16,000,000 - $28,000,000

Notes:

1) Range of total P reduction for all three mills combined, based on qualitative assessments of what effluent TP levels mills may be able to achieve, based on knowledge of WWTP characteristics, past effluent analyses, and limitations of various control technologies. It was assumed that these reductions represent long term averages, and not permit limits, since operating levels would need to be lower than permitted levels to allow for effluent variability.

2) Total cost for all three mills.

3) Capital costs for DAF with chemical precipitation increase with increasing TP reductions due to the requirement for greater sludge handling equipment. Annual O&M costs are also greatly affected by the target phosphorus concentration in the case of chemical precipitation. Lower phosphorus concentrations result in disproportionately higher metal salt concentrations, sludge generation, handling, and disposal, and caustic requirements. The lower costs equate to lower TP reductions, and the higher costs relate to the highest (most stringent) TP reductions.

4) Capital costs were amortized at 7.5% over 15 years and added to annual O&M costs to develop an annual cost of ownership and operation. Capital recovery factor for capital costs is 0.1133 using these assumptions.

5) IP is already adding polymer in the summer months in order to comply with strict summer TSS limits imposed by the Town of Jay. Their costs for polymer addition are not included in this total.

Table 2-2: Summary of Cost Estimates for Various Phosphorus Removal Rates

Reduction Level[1] (Technology Required)	Capital Cost [2]	Annual O&M Cost [2,3]	Annualized Cost [4]
DEP Baseline	$0	$0	$0
1/6 Reduction[1] (PCEs and polymer in sec. clarifiers)	$640,000	$370,000	$440,000
1/3 Reduction[1] (PCEs and DAF with polymer)	$27,000,000	$2,000,000	$5,1000,000
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50% Reduction[1] (DAF with precipitation)	$43,000,000	$16,000,000	$21,000,000
67% Reduction[1] (DAF with precipitation)	$47,000,000	$23,000,000	$28,000,000

Notes:

1) Total P reduction from DEP baseline for all three mills combined. It was assumed that these reductions represent long term averages, and not permit limits, since operating levels would need to be lower than permitted levels to allow for effluent variability.
2) Total cost for all three mills.
3) Capital costs for DAF with chemical precipitation increase with increasing TP reductions due to the requirement for greater sludge handling equipment. Annual O&M costs are also greatly affected by the target phosphorus concentration in the case of chemical precipitation. Lower phosphorus concentrations result in disproportionately higher metal salt concentrations, sludge generation, handling, and disposal, and caustic requirements. The lower costs equate to lower TP reductions, and the higher costs relate to the highest (most stringent) TP reductions.
4) Capital costs were amortized at 7.5% over 15 years and added to annual O&M costs to develop an annual cost of ownership and operation. Capital recovery factor for capital costs is 0.1133 using these assumptions.

3. PHOSPHORUS REDUCTION EXPERIENCE AT OTHER U.S. MILLS

The purpose of this section is to provide a brief summary of TP reduction experience at other mills in the United States. Several mills were contacted to gain an understanding of the strategies they implemented to control their effluent TP concentrations. The following six mills provide a representative cross-section of the experiences at pulp and paper mills with TP limits.

It is extremely important to understand that all mills are different, and there is much uncertainty in predicting how low a mill will perform with respect to P control. Critical factors include: (1) influent pollutant composition and loading rate variability; (2) aeration tank size; (3) sludge age; (4) process control capabilities, including control of P addition to the activated sludge system; (5) operator knowledge and experience; (6) secondary clarifier capacity and loading rate; and (7) ability to control solids loss from the secondary clarifiers.

Two general themes were apparent from our discussions with other U.S. mills that limit P levels in their treated effluent. First, a relatively large, stable treatment system is required to facilitate reduced P addition to the biological treatment system. This facilitates minimal addition of P by: maximizing the time period that the microbes have to work on a limited P supply, minimizing the observed cell yield, maximizing recycle of P from decaying microbes within the system, and absorbing and dampening variations in organic loading. Mills that have relatively small aeration basins with limited sludge ages (e.g. less than 15 days) typically experience difficulty in achieving low effluent P levels. Second, control of effluent TSS levels is absolutely critical to achieving low effluent total P levels. Secondary effluent TSS is typically composed of 1-2 percent P. Therefore, at a typical integrated kraft mill treated effluent TSS level of 20-60 mg/L, the effluent will contain 0.2 to 1.2 mg/L of particulate P. Since pulp and paper mills must discharge some level of soluble P to maintain a healthy biomass, it is very difficult to consistently attain P concentrations less than 1 mg/L. This is consistent with experience at other U.S. mills, and helps explain why P limits for pulp and paper mills in the U.S. are typically 1 mg/L or greater.

Six example experiences of mills that are required to control P in their treated effluent are cited below. Four mills utilize tertiary treatment, one mill has an oversized treatment system, and two mills required relaxed permit criteria after failure to meet their original 1 mg/L permit criteria.

3.1 MENOMINEE PAPERS - TERTIARY TREATMENT AND RELAXED LIMITS

Menominee Papers is a recycle mill in Menominee, Michigan that originally had a 1 mg/L TP limit, which was later changed to 2 mg/L. When the original 1 mg/L limit was implemented in the 1990s, the WWTP reduced their rate of P addition in an attempt to comply with the discharge standard. This resulted in severe polysaccharide bulking and filamentous bulking. The mill then began adding copious amounts of ferric sulfate to their activated sludge system in an attempt to allow increased P addition (for healthy biomass) and P reduction via simultaneous precipitation. This iron salt precipitated too much P from the head of the activated sludge system, and failed to solve the bulking problem. The mill then discontinued adding ferric sulfate and attacked the problem from a different direction. They retrofitted an existing Dissolved Air Flotation (DAF) unit taken from the mill and used it for tertiary solids removal. In addition to providing an average effluent solids concentration below 10 mg/L, the DAF allowed them to appreciably cut back the P addition rate, since filamentous bulking no longer caused high solids losses. Although their effluent P limit was increased to 2 mg/L, the DAF allowed the mill consistently discharge effluent P concentrations below 1 mg/L.

3.2 GEORGIA PACIFIC, GREEN BAY - TERTIARY TREATMENT

The Georgia Pacific, Green Bay, Wisconsin Mill is a recycle mill that was unable to comply with their proposed P limit of 1 mg/L prior to the installation of a tertiary clarifier in 1999. The P:BOD_5 ratio had to be maintained at 0.01 or above to prevent excessive sludge bulking, caused largely by N. limicola III overgrowth. This required that the effluent soluble P concentration be maintained above 3 mg/L, and the effluent total P concentration be maintained above 4 mg/L. The mill was, however, finally able to attain compliance with the 1 mg/L limit once the tertiary clarifier was installed. Ferric sulfate is added prior to the tertiary clarifier to precipitate excess P. The resulting effluent TSS concentration is typically less than 10 mg/L. On the down side, the project was capital intensive, requires appreciable chemical addition, and generates excess chemical sludge.

3.3 MEADWESTVACO, ESCANABA - TERTIARY TREATMENT

The MeadWestvaco, Escanaba, Michigan Mill has a permit limit of 1 mg/L total P. The mill has a massive wastewater treatment plant that includes primary clarifiers followed by a 6-acre lagoon, a 6-acre activated sludge aeration basin, secondary clarifiers, a polishing lagoon and a tertiary clarifier. The tremendous treatment volume provides a long sludge age and a very stable biological operation. Again, this large, stable operation allows the mill the luxury of no P addition. This, coupled with tertiary treatment, allows them to discharge an average P concentration of 0.29 mg/L.

3.4 INTERNATIONAL PAPER, TICONDEROGA - TERTIARY TREATMENT

The International Paper, Ticonderoga, New York Mill is one of the few mills in the country with a total P limit less than 1 mg/L. It is an integrated kraft mill that discharges to Lake Champlain. This limits their allowable effluent P concentration to 0.5 mg/L. The mill consistently complies with this standard, largely because of two factors: (1) the aeration basin is enormous, since it was originally an aerated stabilization basin; and (2) the have large tertiary clarifiers, which are very lightly loaded and sometimes require substantial polymer addition. The large aeration basin provides a long sludge age and associated stable environment to allow limited P addition. Much of the phosphorus used by the biomass is recycled from the settled sludge in the aeration basin. The limited P addition, coupled with tertiary treatment, provides consistently low P concentrations in their treated effluent.

The mill performed bench scale trials on the secondary effluent to determine the feasibility of precipitating soluble P by the addition of iron or aluminum salts. However, this concept was never implemented at full-scale because such high concentrations of metal salts were required.

3.5 GLATFELTER, SPRING GROVE - OVERSIZED WWTP

The Glatfelter, Spring Grove, Pennsylvania Mill has a TP limit of 2 mg/L. This is one of the few mills in the U.S. that complies with a phosphorus limit without the use of tertiary treatment. It is an integrated kraft mill that produces 600 to 700 tons of pulp and 800 to 900 tons of paper (about half of the pulp production of MWV and IP). The plant has with a very forgiving wastewater treatment plant. Their key to discharging final effluent consistently less than 0.5 mg/L total P is tremendous built-in capacity. The mill has four large secondary clarifiers in parallel and an equalization basin with a hydraulic residence time of 24 hours that achieves 50% BOD removal. The resulting solids loading rates in the clarifiers is very low, averaging 8 lb/sf-day (compared to 35 lb/sf-day at MWV-Rumford). This mill doesn't add any P to the wastewater, which results in high Sludge Volume Index levels of 150 to 250 ml/g. Despite the poor settling sludge, the large secondary clarifiers allow sufficient storage of solids to prevent blanket overflow. The result is a very low solids loss and a reported average discharge of 0.2 mg/L total P.

3.6 STONE CONTAINER, ONTONAGON - RELAXED LIMITS

The Stone Container, Ontonagon, Michigan unbleached kraft mill is another mill that had trouble meeting a 1 mg/L total P limit. Even with their relatively long sludge age of 30 days, the conventional activated sludge plant experienced persistent polysaccharide and filamentous bulking issues when they tried to cut back on P addition. They performed jar testing with alum to see if the P could be effectively, and to estimate the cost. Due to aluminum complexation with lignin and other ligands in kraft mill effluent, and the high alkalinity of kraft mill effluent, they discovered that approximately 600 mg/L of alum were required to reduce P to acceptable levels. Furthermore, the resulting residual aluminum concentrations were above the standard for trout toxicity. Rather than pursue the chemical addition route, Michigan regulators ultimately increased the P limit to a mass loading limit that translates into an allowable effluent P concentration of greater than 3 mg/L. Since then, the activated sludge plant has come back under control and discharges TSS in the 30 to 40 mg/L range.

3.7 SUMMARY OF MILL EXAMPLES

Based on our review of other U.S. mills, 1 mg/L is typically the lowest consistently achievable TP permit limit for a conventional activated sludge treatment system, requiring a normal effluent TP concentration of 0.7 to 0.8 to allow for effluent variability. Mills with effluent TP concentrations consistently less than this achieve these levels because their treatment systems were oversized, and/or employed tertiary treatment. Oversized treatment equipment, in the form of large aeration basins and/or secondary clarifiers, allows some mills to operate with very low residual dissolved P concentrations. Tertiary treatment minimizes effluent TSS and particulate P loadings, at substantial cost.

4. CONCLUSIONS AND RECOMMENDATIONS

In summary, we conclude the following:

- A total P permit limit of 1 mg/L is typically the lowest consistently achievable permit limit for a conventional activated sludge treatment system.

- Of the three Androscoggin mills, both MWV and IP often achieve TP levels less than 1 mg/L. The Fraser mill just restarted operations in April 2003 after a 20 month shutdown, with modifications to the previous pulping operations, and therefore will need to operate for several more months before adequate data is available to begin to assess their performance and capabilities.

- Prior to setting permit limits at any of the mills, it is suggested that an additional one to two years of monitoring and data gathering should be implemented. This monitoring period would allow the stakeholders to gain a better understanding of the long-term capabilities of each mill to control phosphorus, and the potential limitations of control technologies that may be applied on a trial basis.

- The construction of DAF systems, while providing the potential to achieve significant TP reductions, would result in substantial capital and O&M costs.

- Effluent TP reductions are possible through more detailed monitoring over a one to two year period, and perhaps the implementation of process control enhancements and polymer addition systems. The data from this study period could then be used to determine the feasibility of future TP reductions.